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REPORT No. 148

THE PRESSURE DISTRIBUTION OVER THE HORIZONTAL TAIL SURFACES OF AN AIRPLANE, III

By F. H. NORTON and W. G. BROWN

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Langley Memorial Aeronautical Laboratory

1. FUNDAMENTAL AND DERIVED UNITS.

	Symbol.	Metric.		English.	
		Unit.	Symbol.	Unit.	Symbol.
Length	l	meter	m.	foot (or mile)	ft. (or mi.).
Time	t	second	sec.	second (or hour)	sec. (or hr.).
Force	F	weight of one kilogram	kg.	weight of one pound	lb.
Power	P	kg.m/sec		horsepower	HP
Speed		m/sec	m. p. s.	mi/hr	M. P. H.

2. GENERAL SYMBOLS, ETC.

Weight, $W = mg$.

Standard acceleration of gravity, $g = 9.806 \text{m/sec.}^2 = 32.172 \text{ ft/sec.}^2$

Mass, $m = \frac{W}{g}$

Density (mass per unit volume), ρ

Standard density of dry air, 0.1247 (kg.-m.-sec.) at 15.6° C. and 760 mm. = 0.00237 (lb.-ft.-sec.)

Specific weight of "standard" air, 1.223 kg/m.^{3} = 0.07635 lb/ft.^{3}

Moment of inertia, mk^2 (indicate axis of the radius of gyration, k, by proper subscript).

Area, S; wing area, S_w, etc.

Span, b; chord length, c.

Aspect ratio = b/c

Length of body (from c. g. to elevator hinge), f.

Coefficient of viscosity, μ

3. AERODYNAMICAL SYMBOLS.

True air speed, V

Impact pressure, $q = \frac{1}{2} \rho V^2$

Lift, L; absolute coefficient $C_L = \frac{L}{qS}$

Drag, D; absolute coefficient $C_D = \frac{D}{qS}$

Cross wind force, C; absolute coefficient $C_C = \frac{C}{qS}$.

Resultant force, R

(Note that these coefficients are twice as large as the old coefficients L_c, D_c.)

Angle of setting of wings (relative to thrust line), i_w

Angle of setting of horizontal tail surface, i_t

Reynolds Number $= \rho \frac{Vl}{\mu}$, where l is a linear dimension.

e. g., for a model aerofoil 3 in. chord, 100 mi/hr., normal pressure, 0°C: 255,000 and at 15.6°C, 230,000;

or for a model of 10 cm. chord, 40 m/sec., corresponding numbers are 299,000 and 270,000.

Center of pressure coefficient (ratio of distance of c. p. from leading edge to chord length), C_P.

Angle of tail setting, $(i_t - i_w) = \beta$

Angle of attack, α

Angle of downwash, ϵ

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ACCELERATED FREE FLIGHT.

SUMMARY.

This report is the third [1] and final part of the investigation on the distribution of pressure over the horizontal tail surfaces of an airplane, conducted by the National Advisory Committee for Aeronautics at the Langley Memorial Aeronautical Laboratory. This part deals with the distribution of pressure during accelerated flight of the full-sized airplane, for the purpose of determining the magnitude of the tail and fuselage stresses in stunting.

As the pressures to be measured in accelerated flight change in value with great rapidity, it was found that the liquid manometer used in the first part of this investigation would not be at all suitable under these conditions; so it was necessary to design and construct a new manometer containing a large number of recording diaphragm gauges for these measurements. Sixty openings on the tail surfaces were connected to this manometer and continuous records of pressures for each pair of holes were taken during various maneuvers. There were also recorded, simultaneously with the pressures, the normal accelaration at the center of gravity and the angular position of all the controls.

This investigation showed the following results:

1. In contradiction to previous beliefs there did not occur in any maneuver on this machine large down loads on the horizontal tail surfaces.

2. In no maneuver was there any down load on the tail plane. The greatest down load on the elevator alone was 3.7 pounds per square foot, which occurred when pulling suddenly out of a dive.

3. The greatest average upload on the horizontal tail surfaces occurred in a tail spin and amounted to 6.6 pounds per square foot.

4. When pulling suddenly out of a dive at 80 miles per hour the normal acceleration at the center of gravity was 3.25 g. and the maximum average tail load (upward) amounted to 5.6 pounds per square foot.

5. When pulling out of a dive the maximum tail load was nearly proportional to the maximum loading on the wings.

6. When pulling as suddenly as possible out of a dive at 80 miles per hour the normal acceleration and the tail load reached their maximum 0.7 second after the stick had reached its most rearward position.

7. In no maneuver was there any appreciable torque about the X axis of the tail plane.

8. If the normal acceleration, the radius of gyration, the position of the center of gravity, the center of pressure on the wings and the approximate angular acceleration is known the tail load can be computed for any maneuver.

9. The most important facor in determining the magnitude and direction of the horizontal tail load for any maneuver is the position of the center of gravity.

[1] See N. A. C. A. Reports Nos. 118 and 119 for Parts I and II.

INTRODUCTION.

IMPORTANCE OF THE PROBLEM.

The study of the tail load in accelerated flight has been considered of great importance, first because there has been no experimental data of any kind upon which the designer could base the strength of the fuselage and tail surfaces, and secondly because it has been believed that the loads experienced by the tail surfaces and fuselage in accelerated flight would far exceed those occuring under any other condition.

PREVIOUS WORK.

There has apparently been no experimental work carried out previously on the study of tail loads in accelerated flight. Reference to some theoretical work on the subject is given below:

Applied Aerodynamics—Thompson, page 263.
Airplane Structures—Pippard and Pritchard, page 54.
Possible Stresses in an Aeroplane in Flight—British R. & M. No. 219.
Structural Analysis and Design of Airplanes—Engineering Division, U. S. Air Service.
Fuselage Stress Analysis—N. A. C. A. Report No. 76.
On the Possible Loading of the Wings and Body of an Airplane in Flight—British R. & M. No. 490.

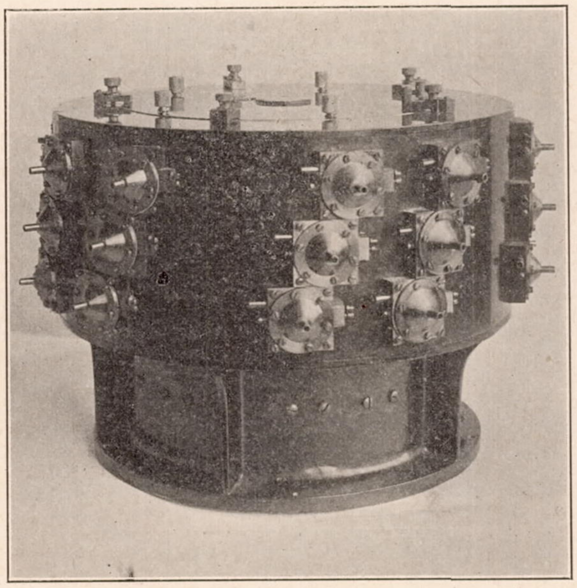


FIG. 1.—N. A. C. A. multiple recording manometer.

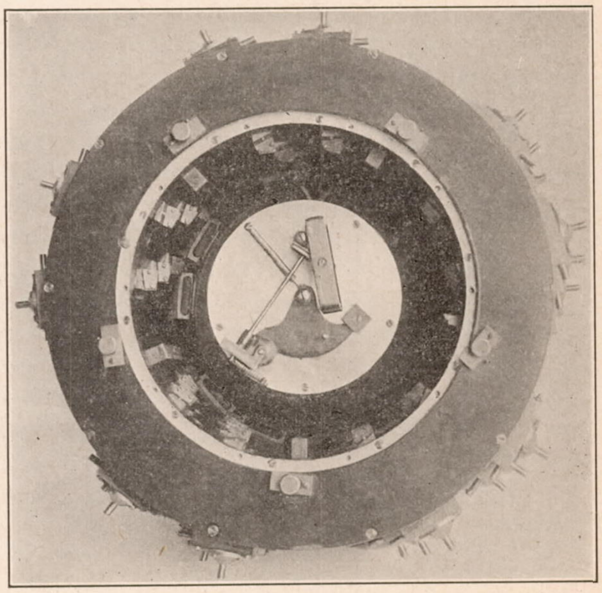


FIG. 2.—Top view of manometer with film drum removed.

THE SCOPE OF THE PRESENT TEST.

The present investigation consisted in measuring on a standard rigged JN4h airplane the distribution of pressure over the whole of the horizontal tail surfaces while the machine was being put through maneuvers as violently as it was thought safe, including spinning and pulling out of dives.

ACKNOWLEDGMENT.

The piloting for this work was done by Mr. T. Carroll, the instruments were installed and calibrated by Mr. Reid, and the computations were made by Mr. Bennett and Mr. Crowley, all of the committee's staff.

APPARATUS.

As the instruments used in this investigation are of a rather novel character, and of possible usefulness in other work, it is thought that a full description of them will be of interest.

MULTIPLE MANOMETER.

The problem of designing a suitable manometer for this work was not a simple one, for there was no standard type that could be modified to fit the conditions. It was necessary to have an instrument capable of recording 30 sets of pressures continuously for 30 seconds, and yet be compact enough to go inside an airplane fuselage. The natural period of the gauges had to be high and there could not be any flow through the connecting tubes with changes in pressure. Finally, the readings must be independent of acceleration and the calibration must not be affected by the vibration of the airplane. These conditions have resulted in the following instrument.

As shown in figures 1 and 2, the separate pressure capsules are arranged around the outside of a cylindrical aluminum casting in three rows of 10. There is located at the center of the bottom of the case an electric bulb with a straight vertical filament. This bulb is inclosed in a chamber having a horizontal annular slit 0.004 inch in width, so that a horizontal sheet of light is spread out in all directions. This light is intercepted when it reaches the inside of the case by 10 long prisms, which send it directly upward to 30 small prisms, which in turn transmit the light through a lens to the mirror on each pressure capsule. The beam of light is reflected back through the same lens, which focuses it sharply on the film.

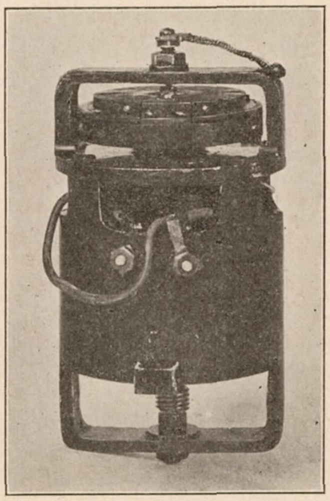


FIG. 3.—Electric driving motor.

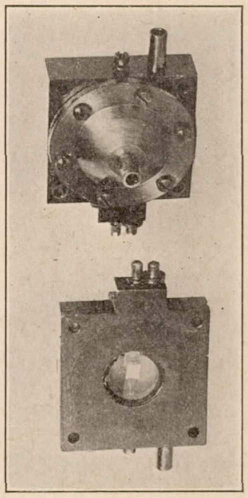


FIG. 4.—Front and rear views of a pressure capsule.

This film has a width of $4\frac{1}{2}$ inches and is wound on a drum 6 inches in diameter. The film drum is mounted in a light-tight case which can be lowered inside of the instrument between the rows of prisms and the driving mechanism. A rotary shutter opens 30 slits for the entrance of the light beam after the film drum is in place.

The film drum is turned through one-tenth of a revolution by a constant-speed electric motor driving through a double-worm reduction gear. The electric motor, shown in figure 3, is the type used in all of the N. A. C. A. recording instruments. It is controlled by a centrifugal governor with electrical contacts which cut in and out a resistance. The speed remains constant within 1 per cent for considerable changes of either voltage or load.

One of the pressure capsules is shown in figure 4. It consists of a brass case divided into two chambers by a hard brass diaphragm with a connection for pressure in either part. The movement of the diaphragm rotates a small plain mirror which is mounted on pivots in much the same manner as in the N. A. C. A. recording air-speed meter.[2] The diaphragm is heated to a higher temperature than the case just before it is clamped into place, so that on cooling it will be tightly stretched; otherwise it has two points of equilibrium which gives an unstable calibration curve. In the center of the front of the capsule there is cemented a small plane

[2] N. A. C. A. Recording Air Speed Meter, Technical Note No. 64.

convex lens, through which the light beam is transmitted. The moving system of the capsule is sufficiently light and well balanced to prevent any acceleration from affecting the pressure readings. The sensitivity of the capsules was so adjusted that they all gave 0.02 inch deflection on the film for 1 pound per square foot change in pressure. For the range of pressures used the deflection was proportional to the pressures and the effect of hysteresis was quite negligible.

One of the extra capsules was connected to a Mark IV Pitot head on the right-hand inner strut. On the corresponding left-hand strut was a similar head connected to an Ogilvie air-speed meter in the forward cockpit. This latter instrument was carefully calibrated over the speed course and used as a reference for calibrating the air-speed capsule during the tests.

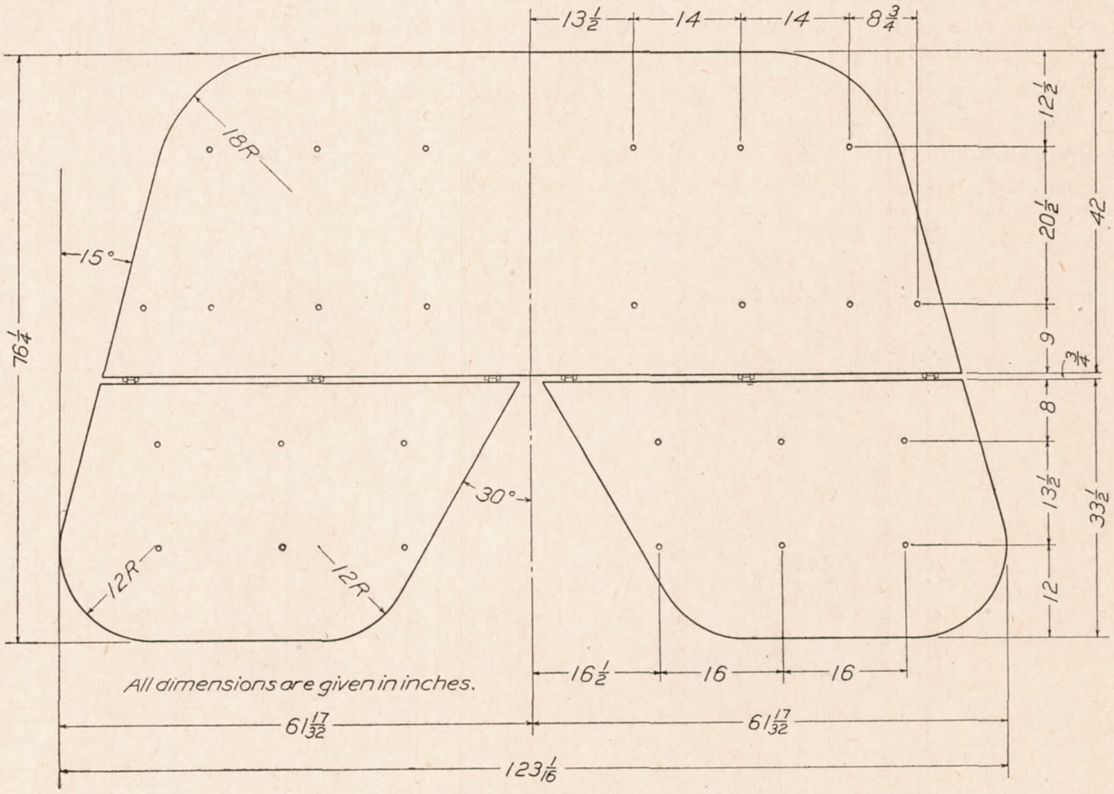


FIG. 5.—Location of the pressure holes on the tail surface.

THE TAIL SURFACE.

The tail surface used was of the standard JN4h type with a distribution of holes as shown in figure 5. It might be thought that the 26 holes used would be insufficient to determine the distribution of pressure accurately, but when it is considered that the previous tests in steady flight have given us the manner of distribution it is evident that sufficient accuracy can be obtained from this arrangement.[3] The first method tried for putting holes in the surface of the tail is shown in figure 6 and consists in soldering the connecting nipple to a very thin sheet of brass which is cemented with dope between a strip of fabric and the outer covering of the tail, after which the outer fabric is perforated above the hole. This method at first seemed very satisfactory, but it was found that after flying for some time the fabric loosened up around the holes and in some cases there was considerable leakage between the hole and the interior of the tail. The method was then changed to that shown in figure 7, which proved to be entirely satisfactory. Great care was taken to be sure that none of the tubes were obstructed and that there was no leakage around any of the holes.

[3] The Drawing of Experimental Curves—N. A. C. A. File 6900-38.

No attempt was made to measure separately the pressures on the upper and lower surfaces of the tail, but only the difference between the pressures in corresponding holes on upper and lower surfaces was measured by connecting the two holes to the opposite sides of a single diaphragm, thus doubling the number of readings that could be taken for a given manometer and also considerably simplifying the computation of the data.

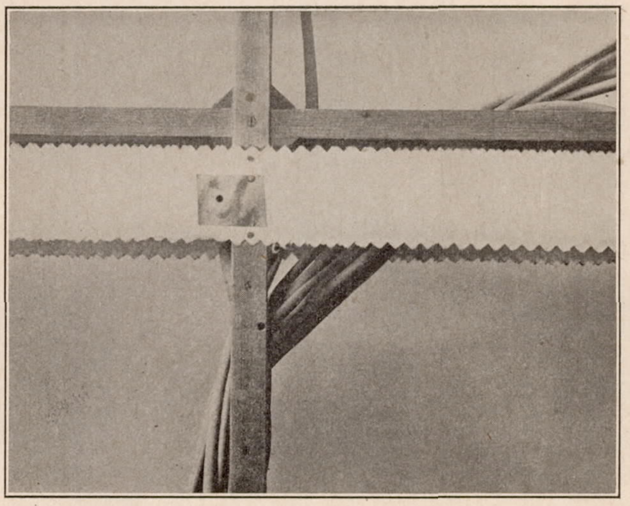


FIG. 6.—First method of constructing the pressure holes.

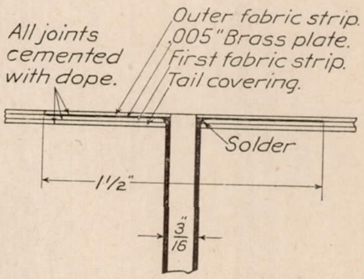


FIG. 7.—The second method used to apply pressure holes in the tail surface.

Due to the weight of the instruments and the rubber tubing in the tail the center of gravity was abnormally far back—46.6 per cent of the mean chord. The pilot, however, did not consider that the machine felt unusually tail heavy, and except for a slight lack of control in landing the handling was normal in every way.

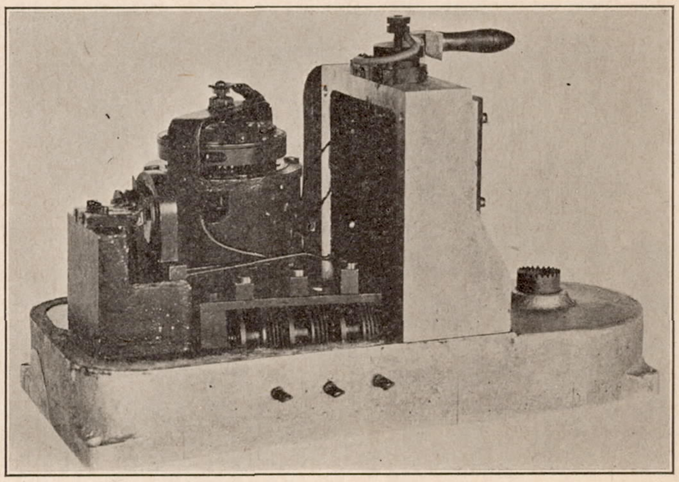


FIG. 8.—Control position recorder.

CONTROL POSITION RECORDER.

It was thought desirable in this investigation to record simultaneously with the other data the position of all three controls. In order to do this the instrument shown in figure 8 was designed. A small steel wire is run from the control horn to the small cords wrapped around three drums inside of the instrument. The drums contain springs to keep the system always at a given tension. These three drums are mounted on a screw so that their rotation

produces a small longitudinal motion which is transmitted to three plain mirrors mounted behind a large diameter lens. The light from an electric bulb is reflected from these mirrors to the usual type of recording drum. As the three records overlap on a film a distinction is made between them by revolving in front of two of the mirrors a sector which produces two kinds of dotted lines.

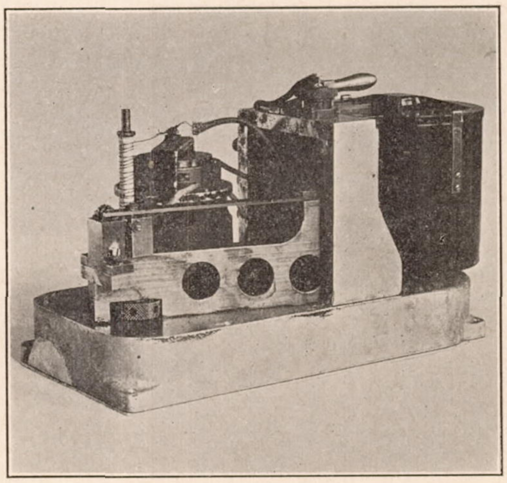


FIG. 9.—N. A. C. A. accelerometer.

ACCELEROMETER.

The accelerometer used in this test is an improved model of the original N. A. C. A. accelerometer described in Report No. 100. The new instrument, figure 9, differs from the old in that it is driven by a constant-speed electric motor and uses oil damping rather than electromagnetic damping. These changes allow a much more compact and convenient instrument.

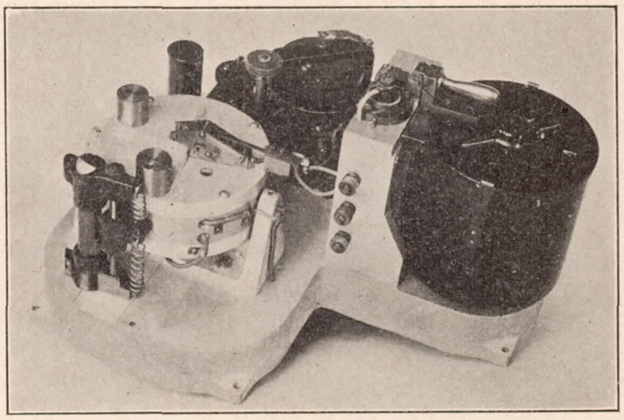


FIG. 10.—N. A. C. A. angular velocity recorder.

RECORDING GYROSCOPE.

As it was thought that records of the angular velocity of the airplane during the various maneuvers would be interesting, the instrument shown in figure 10 was designed. It consists essentially of an electrically driven gyroscope mounted on pivots and restrained from rotation about these pivots by heavy springs. Any angular velocity at right angles to the axis of these pivots will tend to produce a precessional force which is recorded by a small mirror rotated by the movement of the gyroscope case. A complete description of this instrument will be given in a subsequent report.

INSTALLATION.

The multiple manometer was placed on a shelf in the rear cockpit immediately ahead of the observer. The instrument was mounted on a sheet of sponge rubber to prevent the machine vibrations from reaching it. The control position recorder was placed on the face of the rear instrument board so that its drum could be easily changed. The installation of these two instruments is shown in figure 11.

The accelerometer could not be conveniently located at the center of gravity, so it was placed on the floor of the machine about 15 inches directly below this point. The mounting consisted of a heavy block of sponge rubber, to which the instrument was held by means of shock-absorber strands.

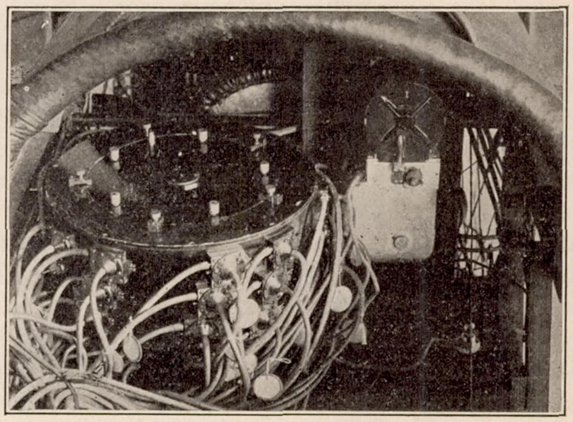


FIG. 11.—The installation of the manometer and control position recorder.

METHOD OF TEST.

SYNCHRONIZATION OF INSTRUMENTS.

The driving motors and the electric bulbs for all three instruments, the mutliple manometer, the control position recorder, and the accelerometer were connected to one switch, so that all the pilot had to do before commencing a maneuver was to close a switch, leave it on for the required period, and then open it. As the driving motors would run for a short time after the switch was turned off, there was left on the record a small space that served to divide the various runs. There was also connected in the circuit a pilot lamp in front of the observer, so that by means of a stop watch he could get the exact time during which the records were taken. As the drums were rotated at uniform speed and the duration of each record was known, it was a simple matter to divide them up into intervals of a second. Since these tests have been completed, a more convenient and accurate method than this has been devised, which consists of an electric chronograph which illuminates a small lamp in the case of each instrument every three seconds, thereby producing a sharp black line across every record at even intervals.

Due to the crowded condition of the airplane, it was inconvenient to place the recording gyroscope in the cockpit at the same time as the other instruments, so that records on this instrument were taken in separate maneuvers. The records from this instrument, therefore, are not strictly comparable with the others, although care was taken to repeat the maneuvers as nearly as possible.

CALIBRATION OF INSTRUMENTS.

Immediately before each flight a zero mark was placed on each record by holding all of the controls in neutral and closing the switch for an instant. After the machine was in the air it was flown steadily at two or three different speeds by the Ogilvie gauge and the switch closed each time for an instant to obtain calibration points for the air-speed meter capsule.

The accelerometer was calibrated in the usual way by turning it on its side and on its back to obtain values of 0 and 1g, respectively.

The multiple manometer was calibrated in the laboratory by connecting all of the pressure capsules to a chamber in which the pressure could be varied. A film was then put in the instrument and a short record made at a number of positive and negative pressures as measured with a water column. The deflections on the film were then measured and a set of calibration curves was plotted. It was found that if the capsules were divided up into two groups their deflections could be measured with sufficient accuracy by using two calibration curves, one for each group. After the tests on the airplane had been completed, the manometer was recalibrated in the same way and it was found that there was no appreciable variation in the calibration curve.

All tests were made at such an altitude that the air density was 0.9, but no density corrections were made to the pressures or to the air speed.

SCOPE OF THE TESTS.

As the chief reason for carrying out this work was to find the maximum load that would occur on the tail surfaces, the machine was put through such maneuvers as were thought to produce the greatest loads, while at the same time not endangering the pilot and observer. The maneuvers selected were the following:

1. The machine was dived at a speed of 80 miles per hour with the motor throttled to about 600 revolutions per minute, and then the stick was pulled clear back as suddenly as possible. When the machine reached a little more than a vertical position the rudder was kicked over and the machine rolled out.
2. The machine was dived as before at 80 miles an hour and the stick was pulled back slowly to its fullest extent and held there until the machine was considerably over the vertical and then it was rolled out as before.
3. The machine was pulled up slowly and at the same time banked in to a sharp left turn from an 80 miles per hour dive with throttled motor.
4. The machine was put into rather a fast right spin in the usual manner, and held there for three turns. The motor was throttled.

Trouble was experienced in the sharp pull up because of the motor cutting out, due probably to a sticking of the carburetor float. As in the first part of this investigation, all the tests were carried out at such an altitude that the density was nine-tenths of standard.

METHODS OF PLOTTING.

The records obtained from the multiple manometer were divided by fine lines into intervals of a second and the deflection of the light beam was read off as it crossed each second interval. These deflections were then multiplied by the calibration constant to give the pressures in inches of water. The values thus obtained were then plotted along each row of holes on the tail in exactly the same manner as was done in Report No. 118. The areas under these curves were then plotted along an axis parallel to the air flow, and the area and center of gravity of this second area gave the total load and the center of pressure on the complete tail plane. The pressures are all given as perpendicular to their respective surfaces and no resolution was made for the angle of the elevator. This was not done, first, because the correction even with large elevator angles is not great, and, secondly, because the load on the elevator was at all times small, so that the resultant correction on the load of the whole tail plane would be within the experimental errors of the results. The angle of the elevator is given, however, for every condition, so that the resolution can be made at any time.

The total load on the elevator and tail plane have also been plotted against a time scale with the curves of control position, air speed, and acceleration for each maneuver.

PRECISION.

PRESSURE READINGS THROUGH SMALL TUBES.

The difficulties of accurately reading a given pressure through a considerable length of small tube during accelerated flight are far greater than for the same readings in uniform flight. For these reasons it was thought desirable to make a very complete study of the errors occur-

ring under the conditions encountered in violent maneuvering. The errors encountered may be divided logically into two parts—the first, errors in time, and the second, errors in the value of the pressure readings.

In order to determine the time lag in transmitting a fluctuating pressure through various lengths and diameters of small tubes the apparatus shown in figure 12 was employed. A small plunger oscillating in a cylinder at the rate of about 30 complete vibrations per second transmits pulsations in pressure to two similar pressure capsules, identical with those used on the multiple

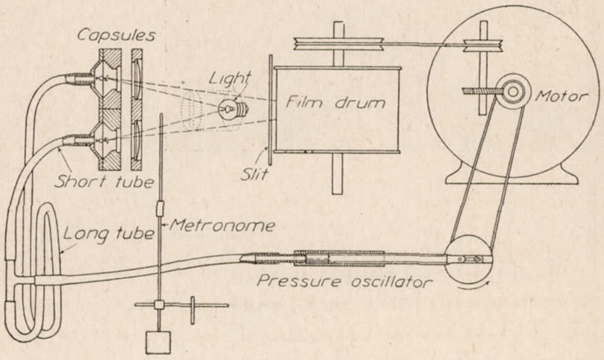


FIG. 12.—Apparatus for measuring pressure lag in small tubes.

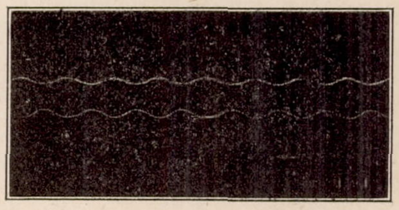


FIG. 13.—Pressure oscillations as recorded on apparatus shown in Figure 12.

manometer. One capsule is connected by a short tube and the other capsule is connected by tubes of various lengths and sizes. A beam of light reflected from the mirrors of these two capsules is focused by a lens upon a strip of moving film, thus producing two sine curves, as shown in figure 13. If the pressures transmitted to the two capsules were carried through tubes of the same length and diameter, the two curves on the film would obviously be in the same phase. If one tube, however, is longer than the other, the curve from that capsule would lag slightly behind the curve from the standard capsule, and this lag is a measure of the time

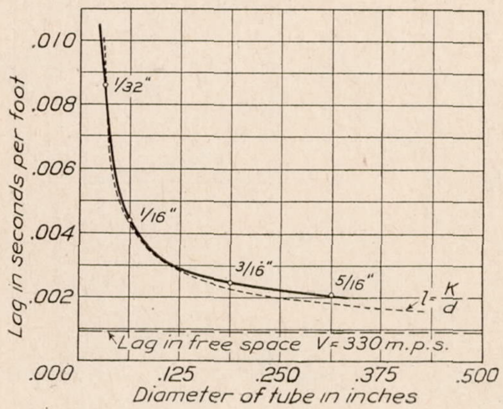


FIG. 14.—Pressure lag in tubes.

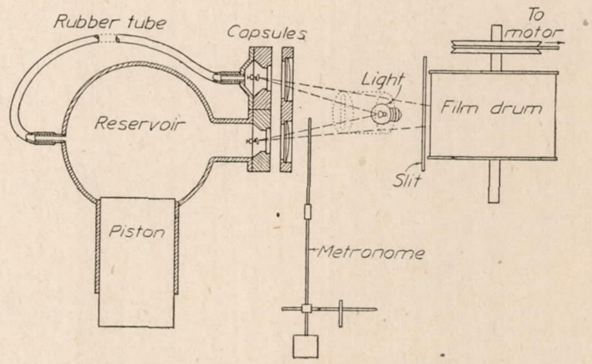


FIG. 15.—Apparatus for measuring the error in pressure reading through small tubes.

taken for the pressure impulse to travel through a length of pipe equal to the difference in lengths between the two connecting tubes.

The results showed that the lag in time was a lineal function of the length of tubes, so that the lag for various diameters of tubes is shown in figure 14 plotted in seconds per foot of length against the tube diameter. Each point is the average of a number of readings on tubes of different lengths. This curve shows two facts clearly—first, that the time lag is quite negligible in airplane work; and second, that the lag per unit length is inversely proportional to the diameter of the tube.

For measuring the error in the magnitude of the pressure readings through tubes the apparatus shown in figure 15 was set up. This consisted of a large reservoir, in the face of which was set one of the pressure capsules with a special back so that the diaphragm was in direct communication with the chamber. A second capsule was connected to the chamber by various lengths and sizes of rubber tubing. The pressure in the chamber was steadily increased from atmospheric up to 13 inches of water in a time of about 1.5 seconds, which

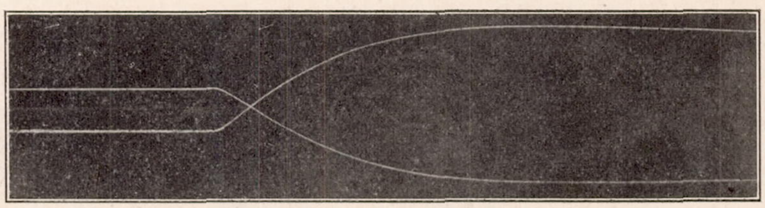


FIG. 16.—Record taken with the apparatus shown in Figure 15.

was as severe a condition as would probably happen in the full-sized airplane. The deflections from both capsules were recorded on a single film as shown in figure 16. Intervals were marked on the film every 0.1 of a second from the beginning of the pressure change, and the deflections of the respective curves were measured at these intervals. The difference between the deflections, after each was multiplied by its proper calibration correction, was the error due to the connecting tube. It was thought that the results could be most clearly represented by plotting this difference as a percentage of the maximum pressure, and this has been done for four sizes of tubes in figures 17 and 18.

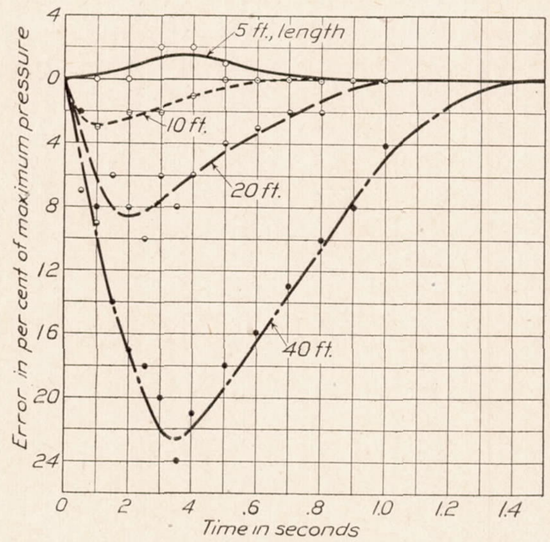


FIG. 17.—Errors in measuring a pressure change through tubes, $\frac{1}{16}''$ in diameter, and of various lengths.

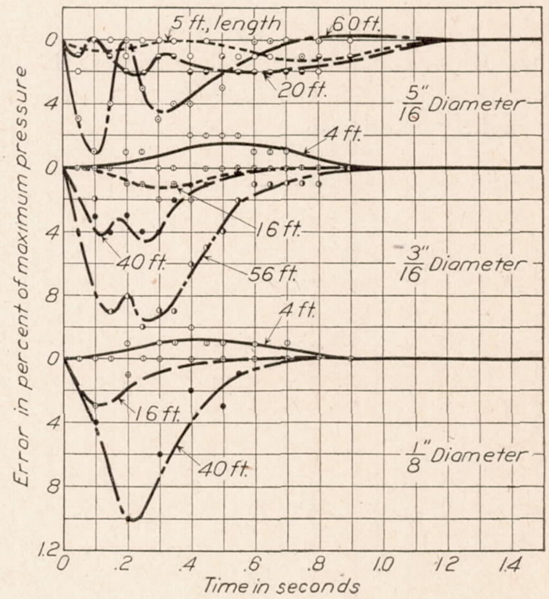


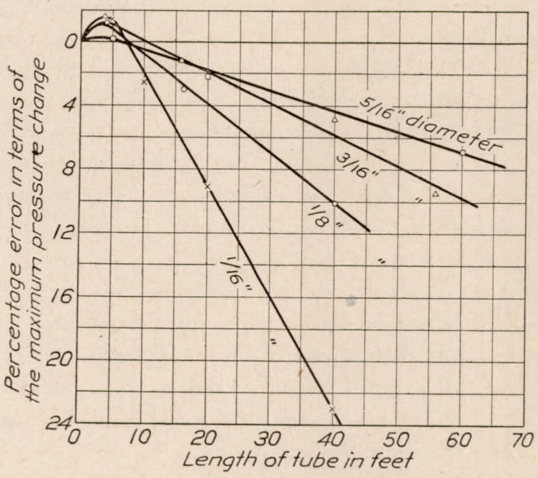
FIG. 18.—Errors in measuring a pressure change through tubes.

It will be observed that in the larger tubes a marked oscillation of the pressure occurs. In the five-sixteenths-inch tube the period of this oscillation is given by $P=\frac{L}{260}$, where P is in seconds and L is in feet. In the smaller tubes the damping is so great that the oscillations are not clearly evident. The results of these curves are probably good to 1 per cent, but the curves are not more consistent because of a slight but rather high period oscillation occurring in the reservoir itself, which gives considerable irregularity to the observed points. The results are replotted in figure 19 to show the maximum error which would occur for different lengths and

diameters of tube used on the pressure capsule. It will be observed that with a pressure rise of 13 inches of water in 1.5 seconds and with a capacity of the pressure capsule of 2.17 cubic centimeters a tube length of 8 feet will give the minimum error which for all sizes of tubes above one-eighth-inch diameter will be less than 1 per cent. For a tube length of 15 feet this error will not rise above 2 per cent. In tubes shorter than 8 feet the pressure reading is too high, due to the inertia effect of the air, and this error is a maximum with a tube length of 4 feet.

It is probable that by using a capsule of a different volume the tube length corresponding to minimum error can be varied. In our tests on the tail plane the tubes used were three-sixteenths inch in diameter and averaged 16 feet in length, so that the error due to transmission of pressure probably did not exceed 1 per cent of the maximum pressure.

There is another error which may come in when using tubes under accelerated conditions, and that is the forces on the column of air in the tube. For example, if we have a tube 10 feet in length which has acting along its axis an acceleration of 3 g the resultant error in pressure will be over 0.4 of an inch of water. In the present investigation this error has been entirely neutralized by running all of the tubes in pairs to opposite points on the tail surface, so that an acceleration acting on one tube will exactly neutralize its effect in the other.



capsule volume change
2.17 cu. cm.
by deflection about 0

FIG. 19.—Maximum error in reading a pressure rising to a maximum in 1.5 seconds, for various lengths and diameters of tubes.

ERRORS IN THE CAPSULE.

The errors in the capsule due to friction, calibration, or hysteresis were less than deflection of 0.01 inch on the film, corresponding to a pressure of 0.5 pound per square foot, which is the precision aimed for throughout.

ERRORS IN PLOTTING AND COMPUTATION.

The errors in plotting the results are somewhat greater than those for the conditions of steady flight because of the fewer number of points. The errors due to this cause, however, should not be greater than 2 pounds on the total load. Considering all of the errors, the total load on the tail plane should be determined in all cases to better than 10 pounds, and in most cases to 5 pounds.

PRECISION OF THE OTHER INSTRUMENTS.

The accelerometer, due to its position below the center of gravity, reads high under some conditions.[4] No correction was made as extreme accuracy in measuring the acceleration was not desired. The values given may be considered correct to 0.1 g.

The positions of the controls are recorded with a precision of 0.5 degree.

[4] Accelerometer Design—Report No. 100.

96934—32——3

The air speed is reduced to standard density and in steady flight is correct to 2 miles per hour, but, as the air-speed head was not swiveling and as the air flow about the wings was uncertain, the air speed in accelerated flight can not be depended upon very closely. For angles of pitch up to 40° the air-speed head has a maximum error of 7 per cent (reads high). This error is probably neutralized to some extent by the banking up of the air around the planes at high angles of attack. The connecting tube used was the same size and approximately the same length as that used for the other pressure capsules, so that the air speed should synchronize with the pressure readings closely.

GENERAL DISCUSSION OF RESULTS.

RAPID FLATTENING OUT FROM A DIVE.

For this case the loads over the entire tail surface for each interval of time are shown in figure 20. The pressures are plotted in exactly the same way and to the same scale as in Report No. 118, but the number of points at which the pressure has been measured is in this case reduced. It will be noticed that at the beginning of the records the results check fairly well with Case I of Report No. 118 and the slight discrepancies can be accounted for by the fact that the conditions are not quite steady and that the center of gravity is farther back on this test.

It is evident from these figures that the load at all times is far more symmetrical on the two halves of the tail than it is in steady flight with the motor at full throttle. At the same time, however, it would be quite unsafe to predict the total load on the tail surface from readings taken only on one side. High peaks of pressure at the outer edges of the tail surface are evident, as in the cases or steady flight. It will be noticed that beyond the seventh second the load on the left-hand side of the elevator is considerably increased due to the left rudder.

In figure 21 there are plotted curves of tail-surface load along the chord, and these curves are comparable with those shown in Report No. 118. Up to a time of two and one-half seconds the loading over the tail surface is approximately normal, but at this time the load all over the elevator and on the rear half of the tail plane is strongly negative, which is caused by the fact that the elevator at this point has been suddenly pulled up to its fullest extent. The moment about the leading edge of the tail plane is rather great at this point—300 foot-pounds. At the third second the down load on the elevator is quite small and the up load on the tail plane has increased, due to the fact that the airplane at this time has started to rotate, thus changing the angle of attack of the tail surface. At three and one-half seconds the up load on the tail plane is very great, but for some unaccountable reason the down load on the rear of the elevator is somewhat increased over the preceding time interval. The tail surface at this time is strongly resisting the stalling moment produced by the wings. After the fourth second the loads on the tail surface become quite normal.

The complete behavior of the airplane while it is being pulled rapidly out of a dive can perhaps be most clearly indicated by referring to figure 22 where there are plotted the following synchronized curves:

1. The air speed of the airplane along the X axis.
2. The normal acceleration at the center of gravity.
3. The angular position of the elevator.
4. The angular position of the ailerons.
5. The angular position of the rudder.
6. The load per square foot on the tail plane.
7. The load per square foot on the elevator.
8. The load per square foot on the total tail surface.
9. The position of the center of pressure of the whole tail surface.

Referring to the elevator position curve, it will be seen that the elevator is moved around irregularly in order to gain the correct speed until a time of 2.2 seconds, when the elevator is pulled back suddenly to its fullest extent in 0.6 second. This position of the elevator is maintained until about the seventh second, when it is pushed gradually forward.

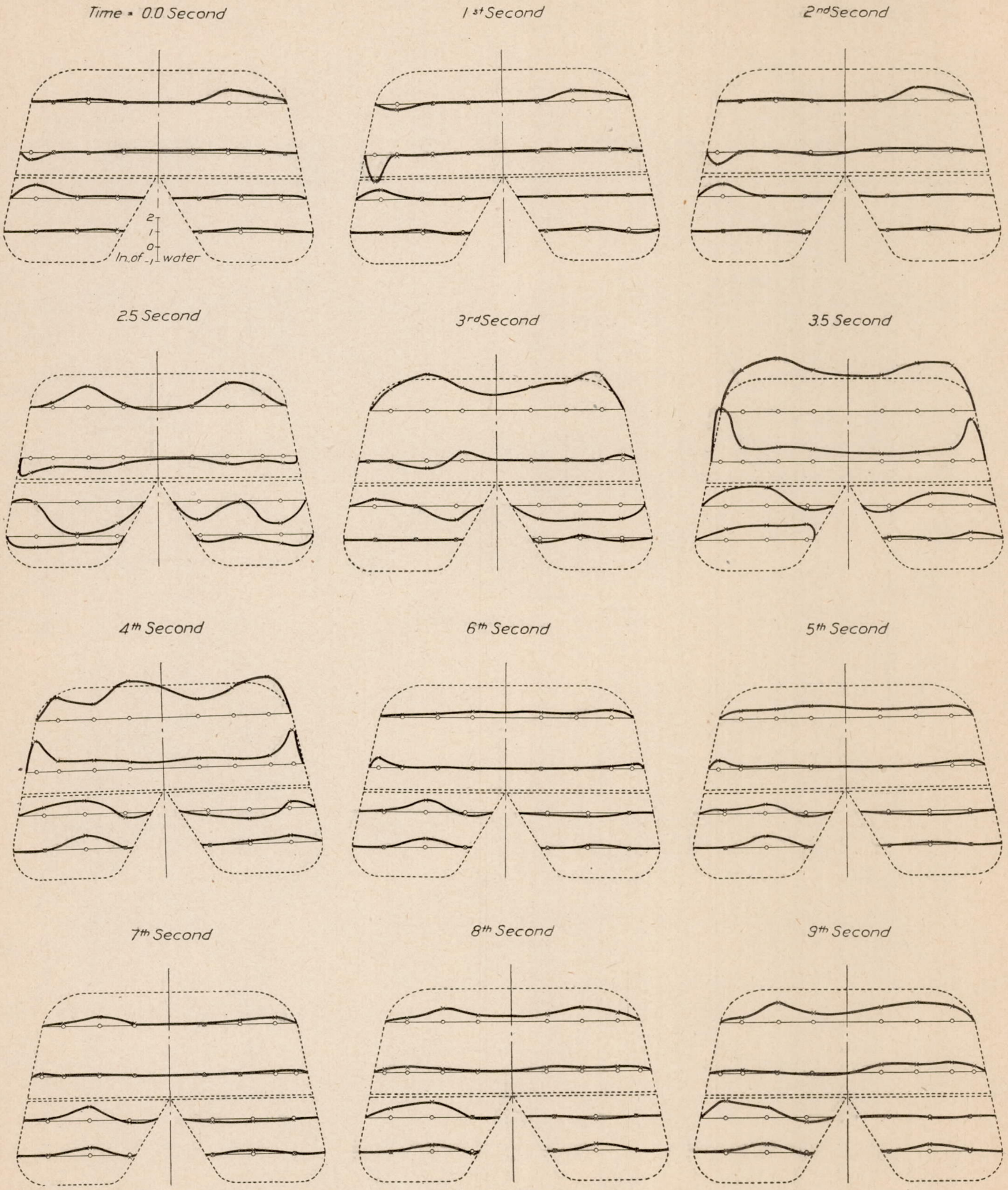
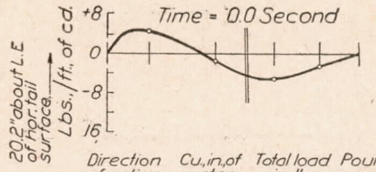
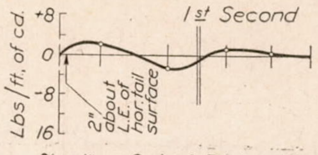


FIG. 20.—Showing the curves of pressure over the entire tail surface for each interval of time in a rapid flattening out of a dive.



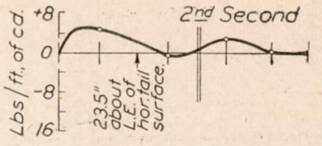
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	+284.76	+10.308	+.3436
Elevator	Down	-583.08	-21.110	-.9500
Total	—	—	-10.800	-.2060

Horizontal tail surface Moment about L.E. = 218"#



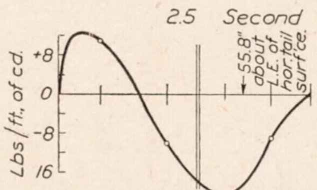
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	0	+13.56	+.491	+.016
Elevator	Up	+94.92	+3.436	+.154
Total	—	—	+3.927	.075

Horizontal tail surface Moment about L.E. = 7.8"#



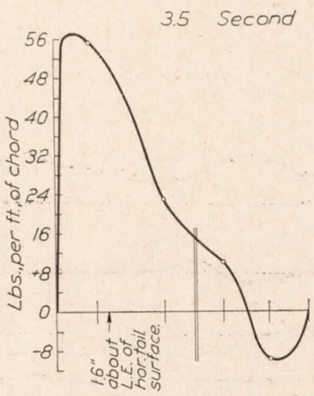
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	+508.50	18.41	.614
Elevator	Up	+213.57	7.73	.348
Total	—	+722.07	26.14	.500

Horizontal tail surface Moment about L.E. = 618"#



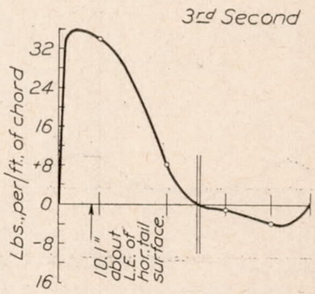
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	118.5	+4.29	.14
Elevator	Down	-2200.0	-79.70	-3.60
Total	—	—	-75.40	-1.45

Horizontal tail surface Moment about L.E. = 4220"#



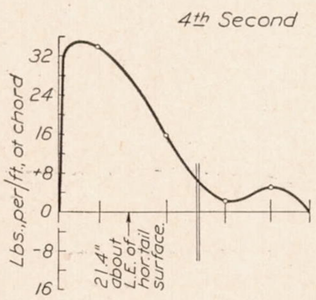
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	+8210.0	+297.00	9.9
Elevator	Down	- 61.2	- 2.21	.1
Total	—	—	+294.79	5.6

Horizontal tail surface Moment about L.E. = 4716"#



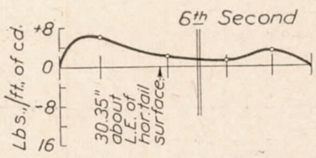
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	4570.	+165.50	5.50
Elevator	Down	380.	-13.75	.62
Total	—	—	+151.75	2.91

Horizontal tail surface Moment about L.E. = 1532"#



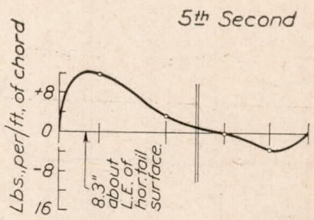
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	+5195.17	+188.07	6.28
Elevator	"	+586.47	+21.23	.95
Total	—	—	+209.30	4.00

Horizontal tail surface Moment about L.E. = 4720"#



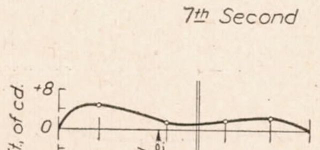
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	791.	28.8	.96
Elevator	"	329.	11.8	.53
Total	—	—	40.6	.78

Horizontal tail surface Moment about L.E. = 1260"#



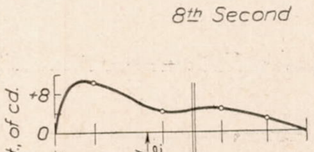
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	+1521.	+55.1	+1.83
Elevator	Down	-251.	-9.1	-.41
Total	—	—	+46.0	.88

Horizontal tail surface Moment about L.E. = 382"#



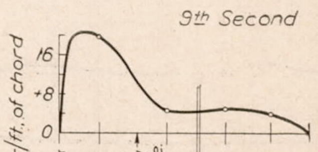
	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	617.0	22.3	.74
Elevator	"	304.4	11.0	.50
Total	—	—	33.3	.64

Horizontal tail surface Moment about L.E. = 1010"#



	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	1440.	52.1	1.74
Elevator	"	542.	19.6	.88
Total	—	—	71.7	1.38

Horizontal tail surface Moment about L.E. = 2002"#



	Direction of action	Cu., in., of water	Total load in lbs.	Pounds per sq. ft.
Tailplane	Up	2490.	89.8	2.99
Elevator	"	667.	24.1	1.08
Total	—	—	113.9	2.19

Horizontal tail surface Moment about L.E. = 2720"#

FIG. 21.—Showing the curves of pressure over the tail surface along the chord for each interval of time in a rapid flattening out of a dive.

The acceleration curve starts in at about 0.8 g and rises slowly to about 0.9 g at the second second while the machine is being nosed down to gain velocity. At 2.2 seconds, exactly the time at which the elevator is started to be pulled back, the acceleration rises rather rapidly until it reaches a maximum of 3.25 g. at 3.4 seconds, which is 0.6 second later than when the elevator reaches its maximum position. From this maximum the acceleration falls very rapidly to a minimum of 0.3 at the seventh second, and after this it rises more slowly to the end of the record.

The air speed shows a gradual increase up to 3.2 seconds, when it falls rather sharply to a minimum of 25 miles an hour at 6 seconds It will be seen that the air speed lags behind the

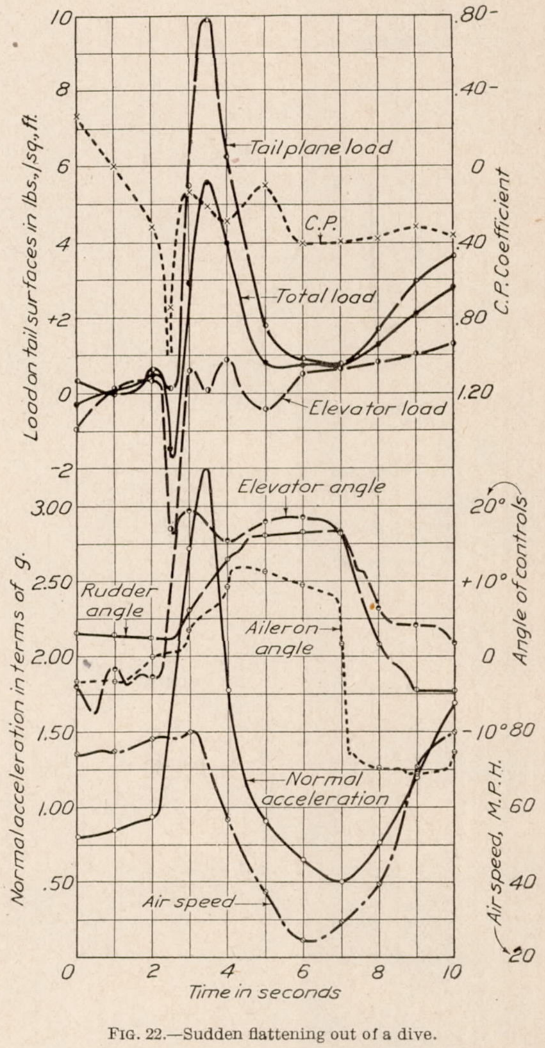
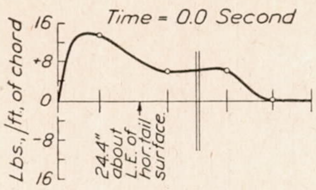


FIG. 22.—Sudden flattening out of a dive.

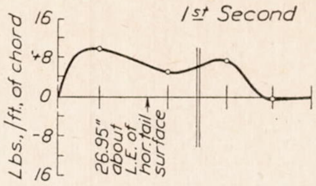
movement of the elevator by approximately 1 second, due to the inertia of the machine. It should be remembered that the air speed as recorded here is only approximate, as there is no way of actually calibrating an air-speed meter under conditions of accelerated flight.

Referring to the load on the elevator, it will be seen that it is slightly irregular but nearly constant in value up to a time of 2.2 seconds, which is the time at which the elevator begins to move upward. After this the load on the elevator falls rapidly to a minimum of -3.7 pounds per square foot at 2.6 seconds. It then rises to -0.5 pound per square foot at 3 seconds, then oscillates between 0 and 1 pound, finally increasing to 1.3 pounds per square foot at 10 seconds. The most interesting fact shown by this curve is that the maximum load on the elevator comes before the elevator is pulled completely back.



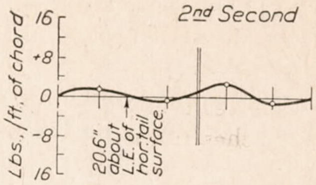
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	+1920.	+69.6	2.32
Elevator	"	+478.	+17.6	.78
Total	—	—	+87.2	1.67

Horizontal tail surface Moment about L.E. = 2120"#



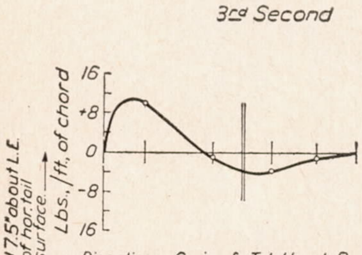
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	1491.	54.1	1.80
Elevator	"	501.	18.3	.82
Total	—	—	72.4	1.38

Horizontal tail surface Moment about L.E. = 1950"#



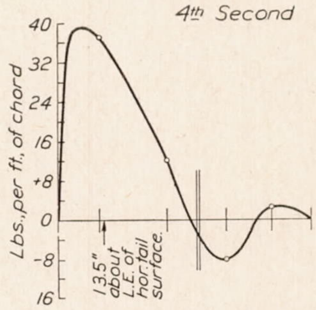
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	81.5	2.9	.10
Elevator	"	108.5	3.9	.18
Total	—	—	6.8	.13

Horizontal tail surface Moment about L.E. = 140"#



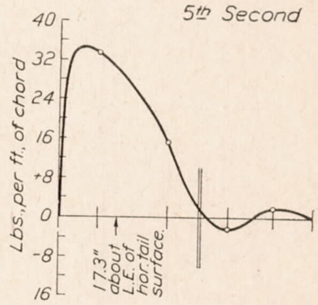
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	+889.	+32.2	1.07
Elevator	Down	-359.	-13.0	.58
Total	—	—	+19.2	.37

Horizontal tail surface, Moment about L.E. = 334"#



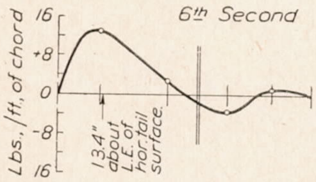
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	+4960.	+179.2	5.97
Elevator	Down	-342.	-12.4	-.56
Total	—	—	+166.8	3.20

Horizontal tail surface Moment about L.E. = 2250"#



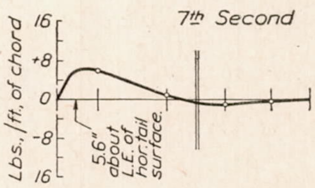
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	+4930.0	+178.50	5.95
Elevator	"	+30.3	+.11	.05
Total	—	—	+178.61	3.43

Horizontal tail surface Moment about L.E. = 3090"#



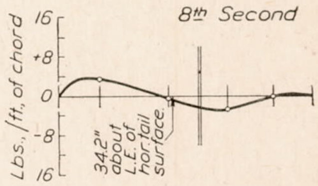
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	+1465.	+53.1	1.77
Elevator	Down	-156.	-5.7	.26
Total	—	—	+47.4	.91

Horizontal tail surface Moment about L.E. = 635"#



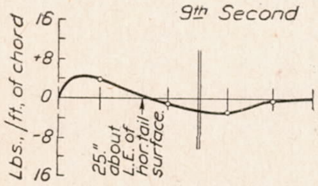
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	802.	+29.10	.97
Elevator	Down	95.	-3.44	-.16
Total	—	—	+25.66	.49

Horizontal tail surface Moment about L.E. = 144"#



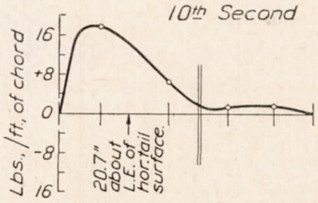
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	+349.	+12.6	.42
Elevator	Down	-189.	-6.8	.31
Total	—	—	+5.8	.11

Horizontal tail surface Moment about L.E. = 198"#



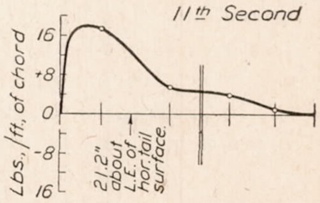
	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	+308.	+11.15	.37
Elevator	Down	-227.	-8.22	.37
Total	—	—	+2.93	.06

Horizontal tail surface Moment about L.E. = 73.3"#



	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	+2360.	+85.60	2.85
Elevator	"	+224.	+8.11	.37
Total	—	—	93.71	1.79

Horizontal tail surface Moment about L.E. = 1935."#



	Direction of action	Cu., in, of water	Total load in lbs.	Pounds per sq., ft.
Tailplane	Up	2386.	+86.5	2.88
Elevator	"	387.	+14.0	.63
Total	—	—	+100.5	1.93

Horizontal tail surface Moment about L.E. = 2130."#

FIG. 23.—Showing the curves of pressure over the tail surface along the chord for each interval of time in a slow flattening out of a dive.

The load on the tail plane is nearly constant until 2.6 seconds, when it rises very rapidly to a maximum at 9.9 pounds per square foot; then it falls more slowly at the the seventh second, and after this slowly rises.

The load on the whole tail surface, which is nearly a mean of the two preceding curves, starts to fall rapidly at 2.2 seconds, reaching a minimum of −1.6 pounds per square foot at 2.6 seconds, then rises rapidly to a maximum of 5.6 pounds per square foot at 3.5, then falls more slowly to 0.8 pound per square foot at the seventh second, and afterwards slowly rises. The most significant fact about this tail load is that except for the brief down load as the stick is pulled back, the load curve follows very closely the curve of normal acceleration. The reason for this will be more fully discussed later in the report.

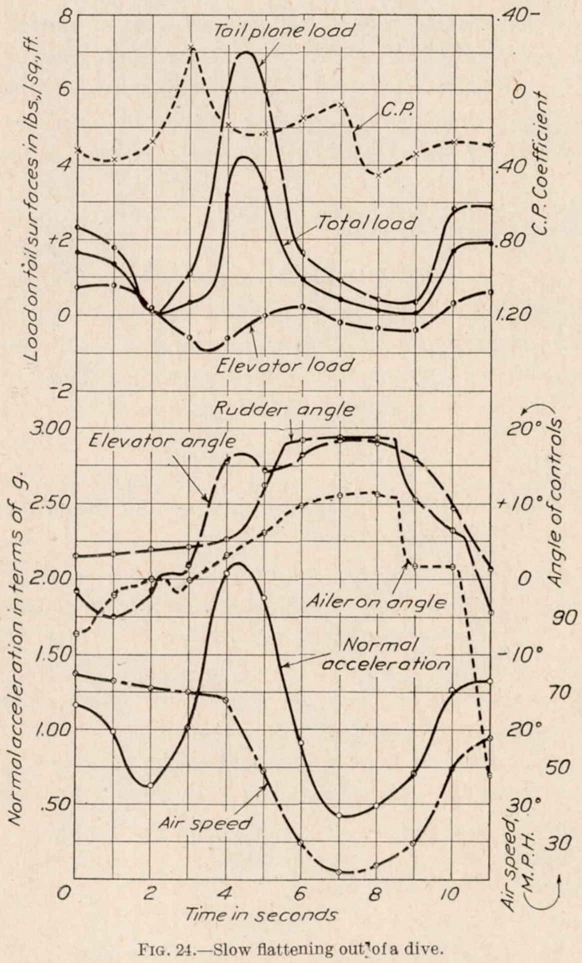


FIG. 24.—Slow flattening out of a dive.

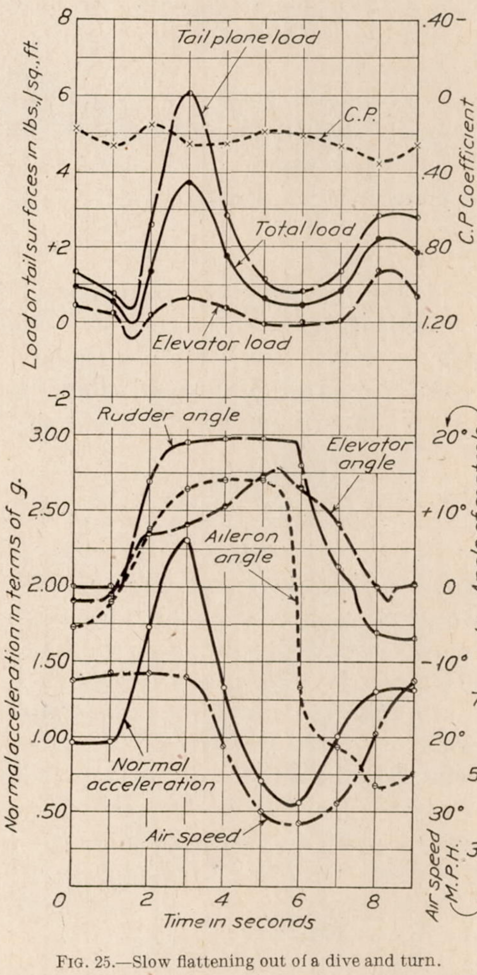


FIG. 25.—Slow flattening out of a dive and turn.

The center of pressure travel is quite irregular, moving off the trailing edge at 2.4 seconds. At the time of maximum load the center of pressure position is 20 per cent back of the leading edge.

SLOW FLATTENING OUT OF A DIVE.

The curves of pressure over the whole tail surface are not reproduced for this case, as they show nothing of interest. The curves of pressure plotted along the chord are shown in figure 23. It will be seen that the load is rather irregular and positive during the first and second seconds as the machine is nosed down to correct a slight bump in the air. At the third second, however, the pressure begins to increase at the nose and decrease at the elevator, and at the fourth second the up load at the nose becomes very high. There is a considerable amount of down load at the hinge and a rather peculiar region of up load at the trailing edge of the elevator.

At the fifth second the distribution of pressure remains practically the same, but at the sixth second the load on the tail plane is considerably reduced and after this time the loading is quite normal everywhere.

In figure 24 there are shown the complete performance curves of the airplane for this case. The elevator is moved slightly forward from zero to the first second and is there pulled slowly back, reaching a maximum at the fourth second. It is held here until the ninth second and then moved slowly forward. The air speed gradually decreases from 75 to 70 miles an hour at the fourth second, then quite rapidly to 22 miles per hour at the seventh second. The acceleration reaches a maximum of about 2.1 g at the same time that the stick reaches its most rearward position, and the peak is much broader than for the quick pulling out of a dive.

The tail-plane load decreases with acceleration to nearly zero at the second second and then rises rather sharply to a maximum of 7 pounds per square foot at 4½ seconds, after which it falls to a normal value. The elevator load decreases slowly to a minimum at 3½ seconds and their ranges about zero for the rest of the run. The load on the whole tail plane reaches a maximum of 4.2 pounds per square foot at the same time that the acceleration is a maximum and then falls off rather rapidly to a normal value. It should be noted that in this case the load on the tail plane is never negative.

SLOW FLATTENING OUT OF A DIVE AND TURN.

As this maneuver was so similar to the last, only the complete performance curves are given in figure 25. The curves are very similar to those of the last case, with the exception that the loads are slightly smaller. The center of pressure remains about 25 per cent back on the chord most of the time. The results show that banking into a turn at the same time as flattening out of a dive imposes no greater stress upon the machine than simply flattening out at the same speed.

TAIL SPIN.

In figure 26 are shown some of the pressure curves on the tail plane during this maneuver. The most interesting thing shown by these curves is the marked unsymmetrical loading which occurs on the elevator, due to the effect of the fin and rudder. In figure 27 are plotted the corresponding curves for the integrated load along the chord. Throughout the spin itself there is a high peak of pressure near the leading edge and a smaller region of up load at the hinge, but the load at the trailing edge of the elevator is very small.

In figure 28 are plotted the complete performance curves for this maneuver. The record begins just as the rudder and aileron are thrown over, but before the machine has responded to them. The air speed at the start is 39 miles per hour and does not begin to increase for 3 seconds because of the sluggish action of the controls under these conditions. The air speed increases from the third to the seventh second rather slowly to 80 miles an hour, which is maintained throughout the spin. In pulling out after the spin, however, the speed increases to a maximum of 100 miles per hour.

The acceleration increases with the air speed and remains nearly constant during the spin at 2.5 g except for a slight oscillation which is evident in all tail spins with this type of machine. As the stick is nosed forward at the thirteenth second to bring the machine out of the spin the acceleration drops considerably, but increases again to a maximum of 3 g. as the machine is flattened out from the resulting dive. The control positions are all nearly constant throughout the maneuver; that is, the stick is pulled back, and the aileron and rudder are both held to the right. Coming out of the spin the stick is pushed forward, the rudder centralized, and the aileron reversed, then all controls are brought back to neutral.

The load on the tail plane starts to increase at about the fourth second to a maximum of 7 pounds per square foot during the spin. The elevator load, however, increases very slowly during the maneuver, reaching the high value of 3.1 pounds per square foot as the machine is pulled out of the dive at the end of the maneuver. The total load on the tail surface increases to about 4 pounds per square foot during the spin itself, but when flattening out of the dive at

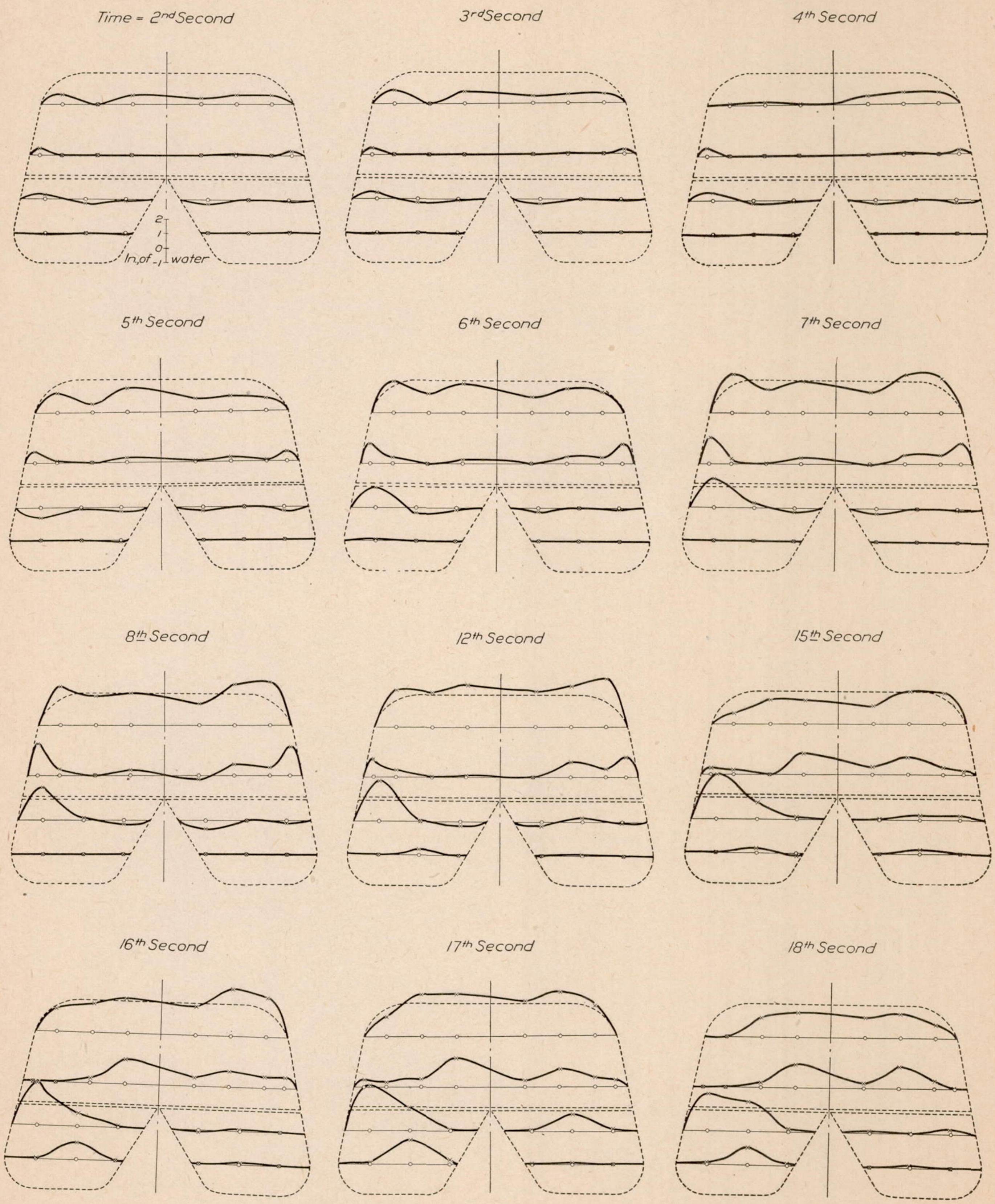


FIG. 26.—Showing the curves of pressure over the entire tail surface for each interval of time in a tail spin.

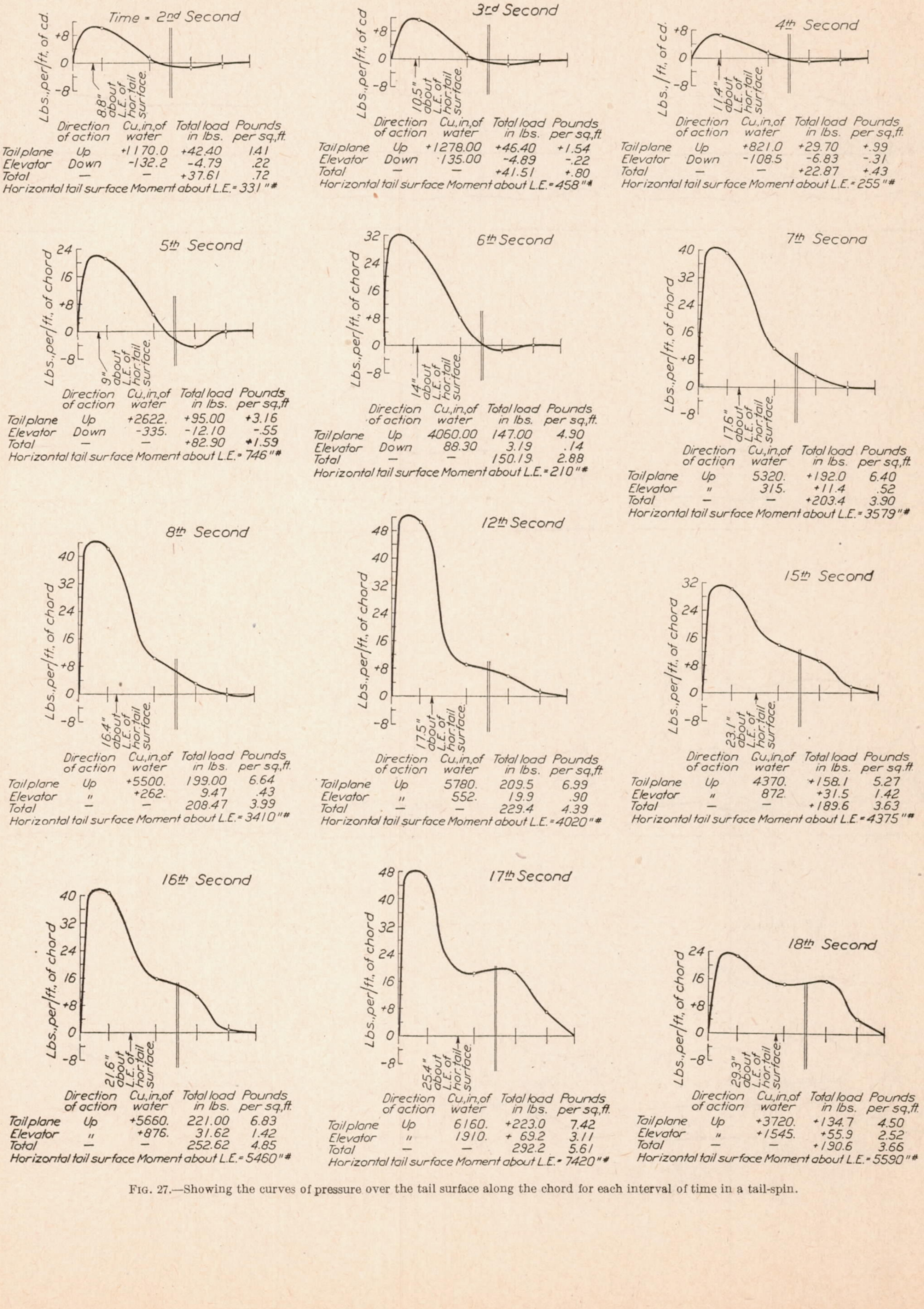


FIG. 27.—Showing the curves of pressure over the tail surface along the chord for each interval of time in a tail-spin.

the end reaches the high value of 6.6 pounds per square foot, corresponding in time to the maximum acceleration.

The results from this case show that the loading in the spin itself is not so great as in flattening out quickly from an 80 mile an hour dive, but that in recovering from the spin the tail load may reach a value somewhat higher than from the former case, although this load is entirely dependent on the way the pilot handles the controls.

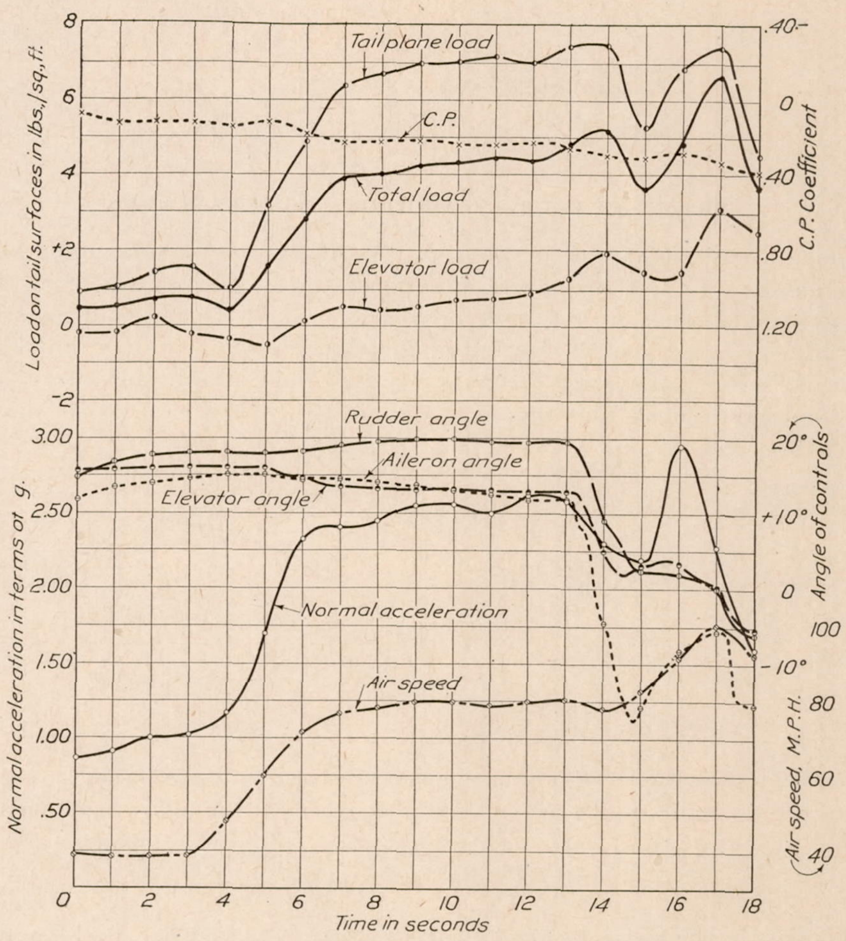


FIG. 28.—Tail spin.

STRESSES DUE TO TAIL-PLANE LOAD.

PRESENT METHOD OF COMPUTING TAIL-PLANE LOAD.

It has been usually assumed hitherto that the horizontal tail surfaces received the greatest load when flattening out of a dive and that this load acted downward. The method of computing this load consisted in assuming that the tail surface reaches its maximum lift coefficient at the time the machine was traveling at its diving speed. The conclusions reached from this method of computing the tail load show that the loading amounts to as much as 40 to 50 pounds per square foot when flattening out of a steep dive.

For example, let us assume that at a given instant the elevator is pulled back 20° and the airplane is diving at 80 miles per hour. Referring to the model tests in N. A. C. A. Report No. 119 we find that the average down loading under these conditions would be 5 pounds per square foot, whereas the actual loading found in this test was only 1.4 pounds per square foot.

On this assumption designers have constructed the fuselage and tail surfaces of sufficient strength to withstand the down load as computed from model tests. Some results are given below on the strength of tail surfaces from sand-load tests on a few well-known airplanes.[5]

Type.	Breaking load in pounds per square foot.	
	Tail plane.	Elevator.
Vought VE-7	40	40
Thomas Morse MB-3	79	53
JN4	75	58
Fokker D-7	69	46

A MORE EXACT METHOD OF COMPUTING TAIL SURFACE LOADS.

As experimental evidence from the present tests shows that the maximum load in flattening out of a dive is actually in the opposite direction from the load computed by the model test method, it is evident that an entirely new method of computing the load must be used. In flattening out of a dive the load on the tail is due primarily to three factors: First, the wing pitching moment; second, the wing damping moment; and, third, the rotary inertia forces. Wind tunnel tests have shown that the second quantity is small, so that we may confine our attention to the first and the last.

FIG. 29.—Forces acting on an airplane.

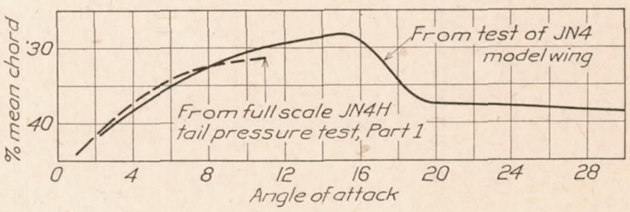


FIG. 30.—Center of pressure travel on wings.

In figure 29 is represented the side view of an airplane with the forces acting upon it. It is evident from this that the total load on the tail is given by the following equation:

$$P = \frac{m}{f+s}(ad + K_B^2 \alpha).$$

Where m is the mass of the plane in slugs, a the acceleration in feet per second acting normal to the wings, d the distance in feet between the center of pressure of the wings and the center of gravity, f the distance in feet between the center of gravity and the leading edge of the tail surface, s the distance in feet from the leading edge of the tail surface to the center of pressure of the tail surface, K_B the radius of gyration, in feet, and α the angular acceleration in radians per second.

In order to try out the validity of this formula there has been computed in the table below the values of the tail load when flattening suddenly out of an 80 miles per hour dive. The values of the accelerations were taken from the first case in this report, and the center of pressure position from the speed and acceleration as well as from the curves given in Report No. 118 and the results of a model test shown in figure 30. The position of the center of pressure at high angles of attack is, of course, only approximate. The angular acceleration unfortunately could not be obtained on the same set of records as the other quantities, so that this was taken on a separate flight in a similar maneuver, so that its precision is not great, although care was taken to synchronize the two records as closely as possible. The radius of gyration of the machine was found in the usual way by swinging it as a pendulum. The damping moment

[5] Structural Analysis and Design of Airplanes. Eng. Div., U.S. Air Service.

due to the wings and body was also computed for a coefficient $u=0.00007$[6] and is tabulated in order to show that the term can be neglected in the equation.

Time.	Air speed.	a/g.	Angle of attack of wings.	d.	α.	f+s.	Damping moment due to wings and body.	Mad.	$-MK^2\alpha$.	P/A calculated from formula.	P/A observed.
1	75	0.85	1.9	−0.24	0.06	13.6	−0	480	−160	0.45	0.10
2	78	.95	1.9	−.24	.06	15.0	−5	430	−160	.35	.50
2.5	79	1.75	6.0	−.59	.80	18.5	−29	2,400	−2,100	.31	−1.45
2.7	79	2.1	8.0	−.69	1.4	13.6	....	3,400	−3,700	−.43	−.30
3	80	2.65	11	−.82	.60	14.5	−152	5,100	−1,500	4.8	2.90
3.5	71	3.25	20+	−.45	.40	15.0	−155	3,400	+1,000	5.6	5.60
4	57	1.75	13.5	−.89	−.48	15.5	−76	3,700	+1,200	6.1	4.00
5	37	.90	20+	−.45	−.26	14.0	−18	990	+680	2.3	.90
6	25	.65	20+	−.45	.24	16.0	−8	680	−630	.06	.75
7	30	.50	12.5	−.87	.25	16.0	−31	1,000	−650	.42	.75
8	40	.75	9.8	−.77	.21	16.0	−54	1,300	−550	1.0	1.35
9	71	1.25	4.4	−.48	−.16	15.5	−83	1,400	+420	1.2	2.15

$M=73$ slugs.
$K_B=6.05$ feet.
$l=13.6$ feet.
Area stabilizer=52 square feet.
Center of gravity coefficient=46.6 per cent mean chord.

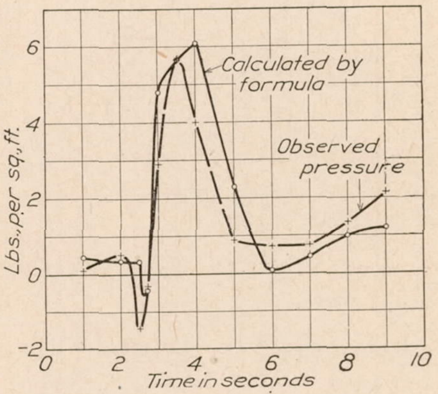


FIG. 31.—Loading on JN4H horizontal tail surfaces for C. G. 46.6 per cent mean chord.

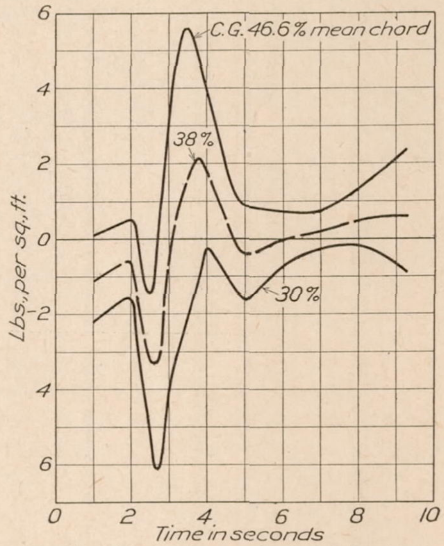


FIG. 32.—Effect of change of C. G. on tail loading.

The computed and observed values for this case of flattening out of a dive are plotted in figure 31. It will be seen that the two curves show a remarkable similarity in shape, and the only discrepancy is that the observed maximum loading comes sooner than the computed maximum, due probably to the fact that the two maneuvers from which the data were taken were not just alike. The computed values, however, come within 2 pounds per square foot of the observed values at all points, and considering the approximate values used in the computation it seems certain that the method can be depended upon to give the tail load accurately.

EFFECT OF THE CENTER OF GRAVITY POSITION ON THE TAIL LOAD.

It is interesting to notice the effect that the position of the center of gravity has upon the tail load. Using the same method of computation as before, the load on the tail when flattening suddenly out of an 80-mile dive is plotted in figure 32 for a center of gravity coefficient at 0.38 and 0.30. As the center of gravity is moved farther forward the load on the tail becomes more and more negative, as would be expected. In order to obtain the minimum stress on the tail

[6] Report No. 17, N. A. C. A.

and fueslage the center of gravity position should be so selected that the maximum up loads and down loads are equal, and this would evidently occur with a center of gravity coefficient of approximately 0.38, which for various other reasons gives a very desirable position for the center of gravity.

RECOMMENDATIONS FOR SAND-LOAD TESTS.

It is evident from these results that with the proper selection of the center of gravity position a unit loading of 1 pound per square foot on the tail surface is sufficient, which would mean a maximum strength of 6 or 8 pounds per square foot on most airplanes. It should be remembered, however, that some of these figures are considerably exterpolated, although there is every reason to believe that they are substantially correct.

In building tail surfaces as lightly as these figures would indicate, great care should be taken, however, to insure proper stiffness, as it seems quite certain that all tail-surface failures

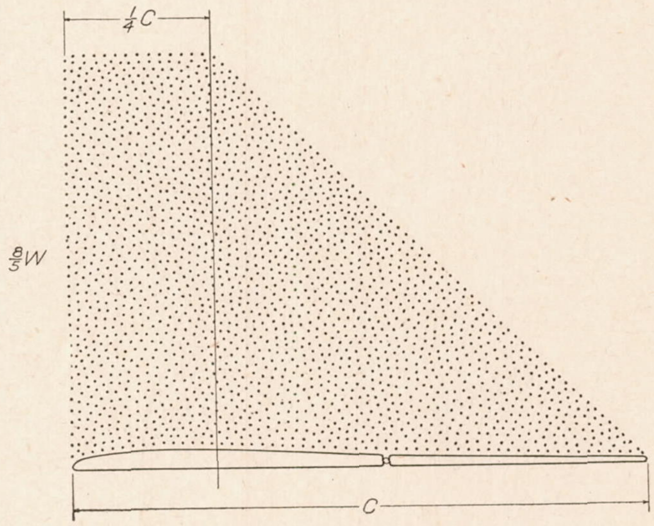


FIG. 33.—Method of sand loading tail surface.

are due to unstable vibrations set up in the structural members. On the whole, it is felt that tail surfaces should stand up to the following sand-load tests:

(1) When the center of gravity coefficient is 0.38, use a unit load of +2 pounds per square foot.

(2) When the center of gravity is back of 0.38, add +0.1 pound per square foot to the unit loading of +2 pounds per square foot for each 0.01 increase in the coefficient.

(3) When the center of gravity is forward of 0.38, add −0.1 pound square foot to the unit loading of −2 pounds square foot for each 0.01 decrease in the coefficient.

(4) The load should be distributed along the chord as shown in Figure 33.

(A positive load is acting upwards as on the wings.)

RECOMMENDATIONS FOR FURTHER RESEARCH.

If further work in carried out to determine the tail-surface loads in accelerated flight it should be along these lines: First, a repetition of the same work done on the JN4h, on a specially built plane at a velocity near the terminal diving speed; second, a series of tests on a single machine with various positions of the center of gravity; and, third, pressure distribution over the wings for a more accurate determination of the center of pressure on the wings. The first test will give loads much greater than is possible or safe on the JN4h, and will be valuable as a check on the general conclusions deduced from the results on one machine. The second test will be valuable in finding closely the center of gravity position for a minimum tail load and to

check up the conclusions arrived at in this report. The third test will make it possible to calculate the tail loads much more accurately than at present.

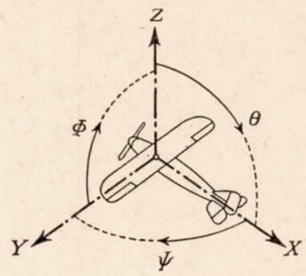
As to the instruments, there are no changes desirable except the inclusion of the angular velocity recorder with the other instruments. On the whole, the instruments functioned very successfully. Their reliability is especially important, as the failure of any one of them invalidates the whole test.

CONCLUSIONS.

The results of these tests show that tail loads can not be computed from model tests. This is due to the fact that the airplane begins to rotate as soon as the elevator begins to be pulled up, thus relieving the load before it can build up. The tail load necessary to produce an angular acceleration is small compared with that necessary to balance the pitching moment of the wings.

The method of calculation based on the wing pitching moments and the angular acceleration gives the tail loads closely in any maneuver where the speed, normal and angular acceleration, and center of gravity position are approximately known.

It seems evident from these tests that the strength of fuselage and tail surfaces on the present machines is excessive, and that a considerable saving in weight can be made.



Positive directions of axes and angles (forces and moments) as shown by arrows.

Axis.		Force (parallel to axis) symbol.	Moment about axis.			Angle.		Velocities.	
Designation.	Symbol.		Designation.	Symbol.	Positive direction.	Designation.	Symbol.	Linear (component along axis).	Angular.
Longitudinal	X	X	rolling	L	Y ⟶ Z	roll	Φ	u	p
Lateral	Y	Y	pitching	M	Z ⟶ X	pitch	θ	v	q
Normal	Z	Z	yawing	N	X ⟶ Y	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_l = \frac{L}{q\,b\,S}, \quad C_m = \frac{M}{q\,c\,S}, \quad C_n = \frac{N}{q\,f\,S}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS.

Diameter, D

Pitch (a) Aerodynamic pitch, p_a

(b) Effective pitch, p_e

(c) Geometric pitch, p_g

Pitch ratio, p/D

Inflow velocity, V′

Slip-stream velocity, V_s

Thrust, T

Torque, Q

Power, P

(If "coefficients" are introduced all units used must be consistent.)

Efficiency $\eta = T\,V/P$

Revolutions per sec., n; per min., N.

Effective helix angle $\Phi = \frac{V}{\pi\,D\,n}$

5. NUMERICAL RELATIONS.

1 HP = 76 kg. m/sec. = 550 lb. ft/sec.

1 kg. m/sec. = 0.01315 HP

1 mi/hr. = 0.4470 m/sec.

1 m/sec. = 2.237 mi/hr.

1 lb. = 0.4536 kg.

1 kg. = 2.204 lb.

1 mi. = 1609 m. = 5280 ft.

1 m. = 3.281 ft.

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